Magnetic Field Vector Measurements Using Doppler-Free Saturation Spectroscopy

FUSION Diagnostics Program Review (Virtual)
March 5, 2021

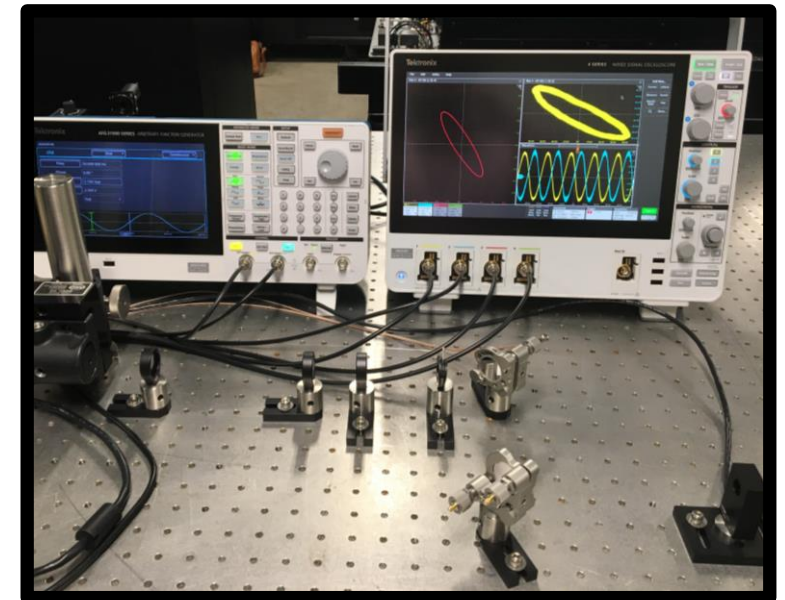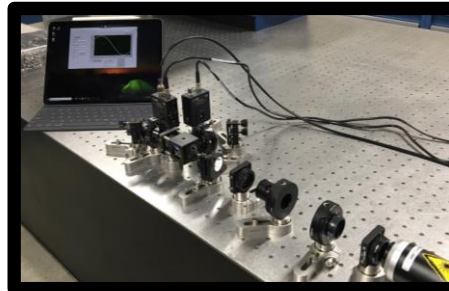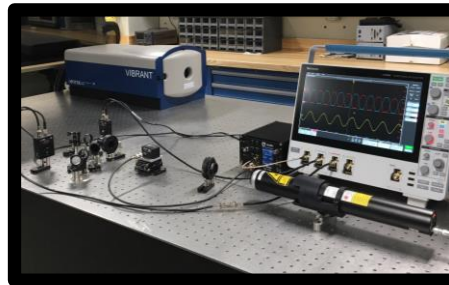Elijah H. Martin, Oak Ridge National Laboratory

David C. Donovan, University of Tennessee – Knoxville

Team members and roles

▸ Elijah H. Martin
  – Diagnostic design and assembly
  – Performance verification via laboratory demonstration
  – Identification of concept teams

▸ David C. Donovan
  – Subsystem performance verification

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CHANGING WHAT'S POSSIBLE

High-level motivation and capabilities of the DFSS diagnostic

Provide experimentally measured equilibrium B-field data needed to optimize and accelerate the fusion-concept.
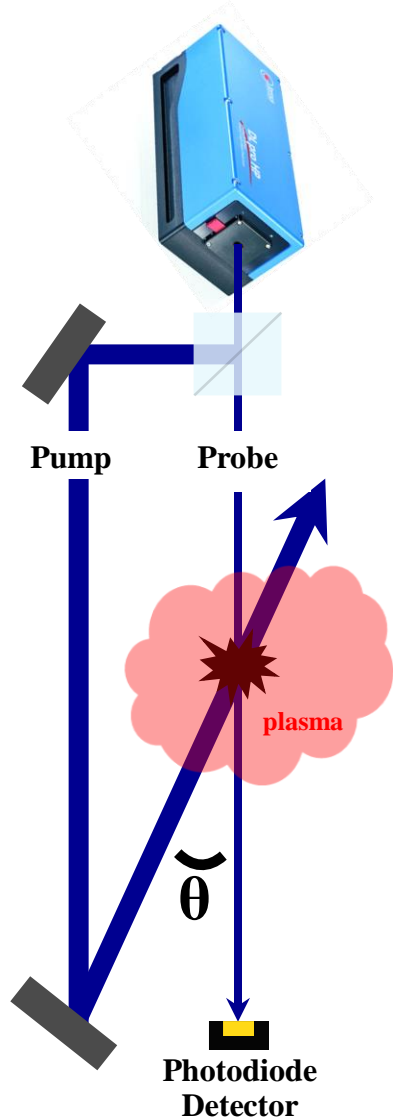
Applicability

1. Atomic H/D neutrals ($\geq 10^{10}$ m^{-3})

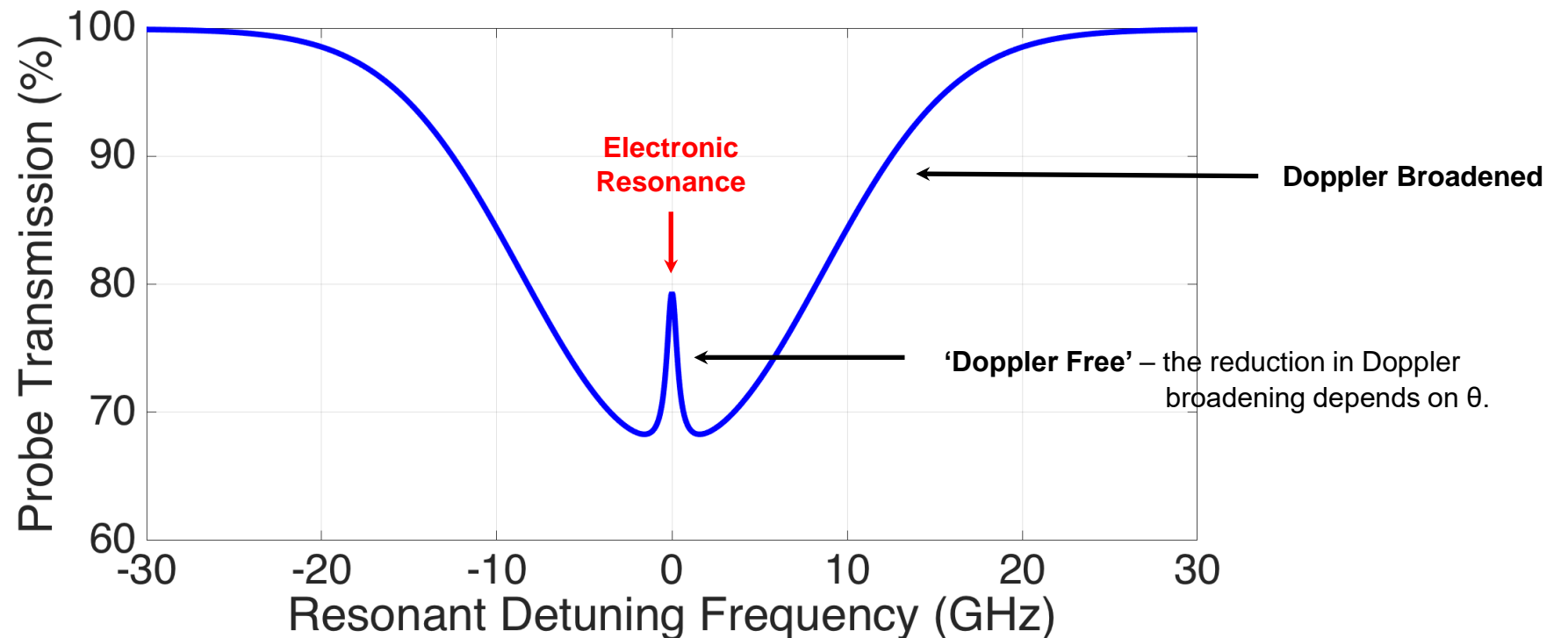2. Optical access at two locations

3. B-Field $\geq$ 10 to 20 Gauss

Capability

1. $B_\parallel$ magnitude/polarity (±5 Gauss)

2. $B_\perp$ magnitude (±5 Gauss)

3. mm ($\perp$) to cm ($\parallel$) resolution

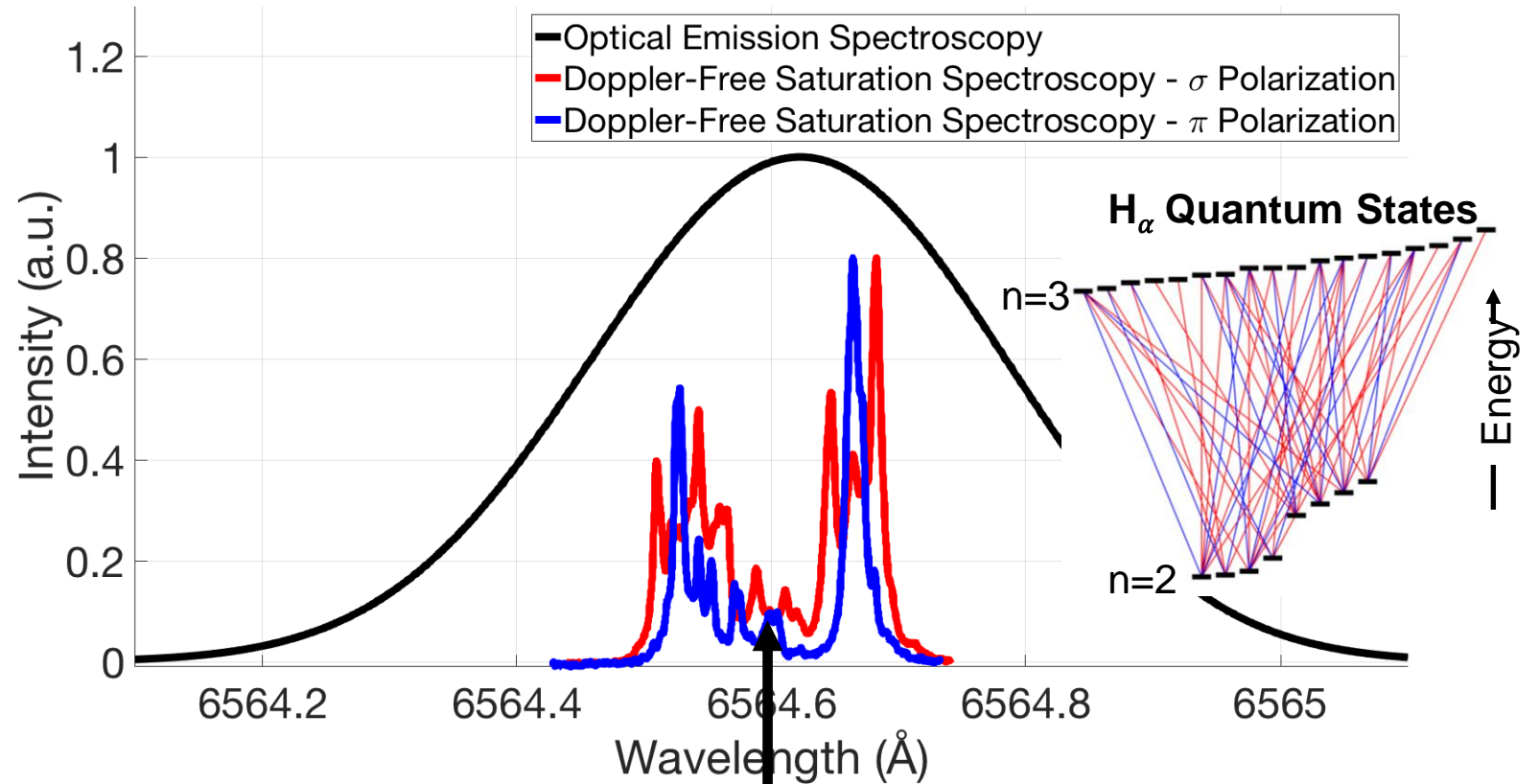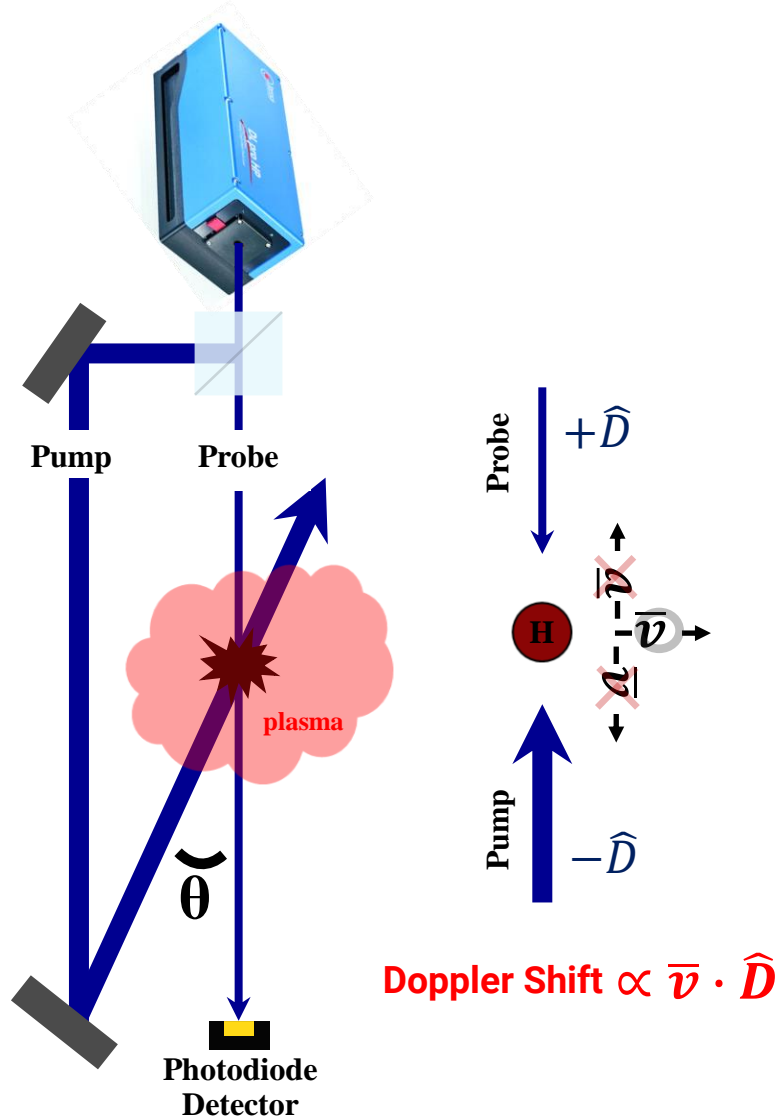4. 5 to 20 ms temporal resolution

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Physics of DFSS

I. Two laser beams are generated from a single source, these beams are referred to as the **pump** and **probe**.

II. The beams are aligned such that they are counter-propagating at a small angle (θ=1-3°) and overlap at the desired measurement location.

III. The probe beam intensity is measured as the laser frequency is swept.

Pump   Probe

plasma

θ

Photodiode
Detector

**Electronic
Resonance**

Doppler Broadened

'Doppler Free' – the reduction in Doppler
broadening depends on θ.

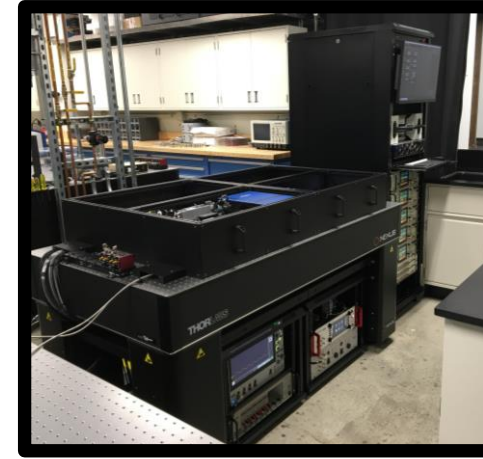Probe Transmission (%)

Resonant Detuning Frequency (GHz)

# DFSS selectively accesses atoms in velocity space

DFSS design

- ▸ System consists of:
  - – 3' x 6' optical table
  - – 19" equipment rack
  - – Two mobile optical tables (2' x 2')

- ▸ Laser is connected to mobile optical tables via PM fiber

- ▸ Mobile optical tables:
  - – Shape and steer the pump beam
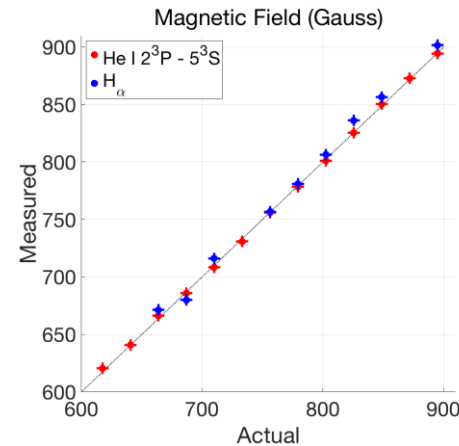 - – Shape and collect the probe beam
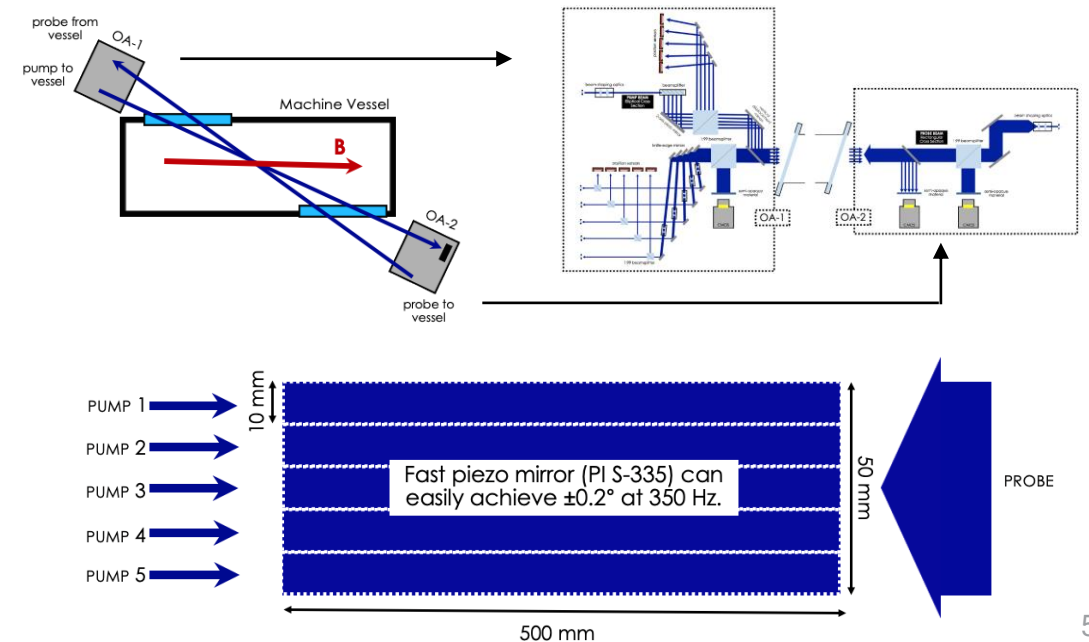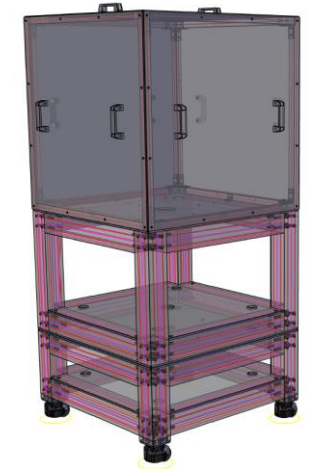
DFSS performance verification

▶ The performance of the DFSS diagnostic will be verified using an existing magnetized plasma test stand at ORNL.
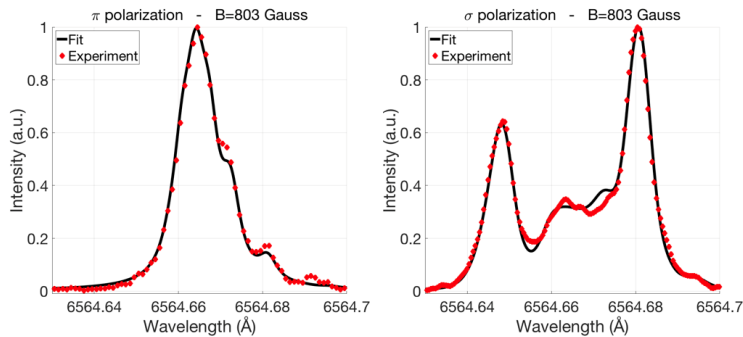
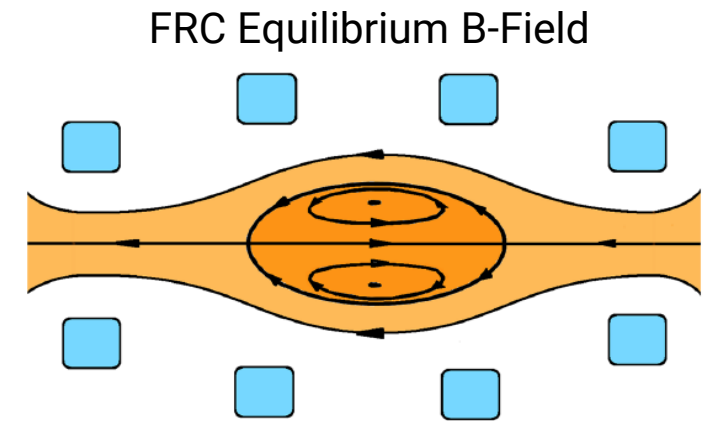$$i\hbar\frac{\partial \Psi}{\partial t} = \hat{H}\Psi$$

FIT ➡

Plasma Test Stand

▶ Performance metrics:

– 2D measurement of known magnetic field with <10 Gauss accuracy

– Temporal resolution: 5 to 10 ms (localized) and 0.5 to 1 s (2D)

– Spatial accuracy: 1's mm

Deployments to fusion experiments

▸ Two deployments have been funded through the INFUSE program:

  – **TAE Technologies Inc.** – **C-2W**
    • Deployment scheduled for July 2021

  – **Princeton Fusion Systems** – **PFRC-II @ PPPL**
    • Deployment scheduled for early 2022

▸ Future deployments (unfunded):

  – **University of Wisconsin, Madison** – **WHAM**

FRC Equilibrium B-Field

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